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INSPECTION AND ANALYSIS OF FAILED TRANSMISSIONS

INTERIM REPORT
TFLRF No. 399

by
Adam C. Brandt
Edwin A. Frame

U.S. Army TARDEC Fuels and Lubricants Research Facility
Southwest Research Institute® (SwRI®)
San Antonio, TX

for
U.S. Army TARDEC
Force Projection Technologies
Warren, Michigan

Contract No. DAAE-07-99-C-L053 (WD51)

June 2009

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14. ABSTRACT
Three Allison Transmission Incorporated (ATI) 2500-SP transmissions failed in service OCONUS, and were shipped to US Army TARDEC Fuels and Lubricants Research Facility for tear down and inspection. Each transmission was completely disassembled and components inspected and rated in an effort to determine the overall cause of failure. Used fluid samples were collected from each transmission and analyzed to classify the types of fluid that were in use during failure. Upon completion of work, a parts inspection meeting was hosted at Southwest Research Institute for representatives from TARDEC and ATI.

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EXECUTIVE SUMMARY

Three Allison Transmission Incorporated (ATI) 2500-SP transmissions were shipped to the US Army TARDEC Fuels and Lubricants Research Facility for failure analysis. Transmissions were removed from RG31 Mine Resistant Ambush Protected (MRAP) vehicles that were reported to have little to no acceleration. All vehicles were located OCONUS. Information was also provided that failed units could have been changed over to a MIL-PRF-2104 oil during service. The following transmissions arrived for teardown and inspection:

- SN 6310824455 – Date Code E7KO2
- SN 6310817160 – Date Code 07JO4
- SN 6310817719 – Date Code 07JO5

All transmissions were completely disassembled, and internal components were visually inspected by TFLRF staff and ATI certified technicians. From the initial visual inspection, it was evident due to the discoloration of the torque converters and melted plastic speed sensors, that the transmissions had experienced high temperatures. The condition of all driveline critical components were rated based on comparison with new, unused components. In addition, torque converters were cut open and internal components were inspected. Fluid samples collected prior to disassembly were analyzed to determine their characteristics in an effort to determine if the fluid was consistent with used engine oils or that of transmission fluids.

A damaged or malfunctioning stator assembly was indentified within each transmissions torque converter. The stator assembly is used to redirect the fluid leaving the turbine back into the pump at high differential pump and turbine speeds creating torque multiplication. In an event of a freewheeling stator, the stator cannot redirect the fluid resulting in little to no acceleration of the vehicle. From the used oil analysis, no evidence of engine oils were found to be present. Results from the oil analysis were found to be consistent to that of used Dexron or TES-295 automatic transmission fluids.

A parts inspection meeting was held for representatives from TARDEC and ATI. Parts were inspected, and discussions were held regarding the MRAP vehicle and transmission application, as well as details regarding the overall failure. It was the opinion of the ATI representatives that the problems experienced were not a result of fluid incompatibility. This supports findings by TFLRF. In addition, ATI requested access to two of the three used torque converters for future analysis.

FOREWORD/ACKNOWLEDGMENTS

The U.S. Army TARDEC Fuels and Lubricants Research Facility (TFLRF) located at Southwest Research Institute (SwRI®), San Antonio, Texas, performed this work during the period November 2008 through January 2009 under Contract No. DAAE-07-99-C-L053. The U.S. Army Tank-Automotive RD&E Center, Petroleum and Water Business Area, Warren, Michigan administered the project. Mr. Luis Villahermosa (AMSTA-RBFF) served as the TARDEC contracting officer's technical representative.

The authors would like to acknowledge the contribution of the TFLRF technical support staff, consultation from SwRI technical advisor Ray Townsend and US Army TARDEC Fuels and Lubricant Research Facility Director Steve Marty, as well as administrative and report-processing support provided by Dianna Barrera.

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ACRONYMS AND ABBREVIATIONS

ASTM	American Society for Testing Materials
ATI	Allison Transmission Incorporated
avg	Average
Ca	Calcium
cSt	Centistokes
Cu	Copper
Fe	Iron
FTIR	Fourier Transform Infrared
ICP	Inductively-coupled plasma
lb	Pound
Mg	Magnesium
MRAP	Mine Resistant Ambush Protected
OCONUS	Outside the Continental United States
P	Phosphorus
Pb	Lead
ppm	Parts per million
SwRI	Southwest Research Institute
TAN	Total acid number
TARDEC	Tank-Automotive RD&E Center
TBN	Total base number
TFLRF	U.S. Army TARDEC Fuels and Lubricants Research Facility
Zn	Zinc

1.0 INTRODUCTION AND BACKGROUND

The US Army TARDEC Fuels and Lubricants Research Facility (TFLRF) received information on multiple transmission failures occurring in RG31 mine resistant ambush protected (MRAP) vehicles. All failures occurred in vehicles located OCONUS. Limited information was available on the description of the failure mode or information regarding vehicle servicing and maintenance. It was noted that transmission failures occurred with limited vehicle use, and the possibility existed that failed units could have been filled with a MIL-PRF-2104 oil. Information regarding the failure description was limited to vehicles exhibiting little to no acceleration.

Three reportedly failed Allison Transmission Incorporated (ATI) 2500-SP transmissions were shipped from the OCONUS location to Red River Army Depot in Texarkana, TX and then forwarded to Stewart and Stevenson LLC located in San Antonio, TX. Each transmission was disassembled and inspected by Stewart and Stevenson ATI certified technicians and TFLRF staff. The following is a list of transmissions that were received and inspected:

- SN 6310824455* – Date Code E7KO2
- SN 6310817160* – Date Code 07JO4
- SN 6310817719* – Date Code 07JO5

**For simplicity, the last three digits of the serial number will be used to refer to each unit.*

TFLRF staff's role was to determine the overall cause of transmission failure, and determine if failure was attributable to the type of fluid used.

2.0 PROCEDURE

Each transmission was disassembled and inspected by TFLRF staff and ATI certified technicians at Stewart and Stevenson LLC. Prior to disassembly, used fluid samples were collected from each transmission drain pan for used oil analysis. Transmissions were then

completely disassembled, and all components received a detailed visual inspection. Components of interest were measured and compared to published specs provided by ATI for new and used components. These components included the torque converter, main oil pump, shift solenoids, and pressure transducers. After disassembly, all components were shipped to TFLRF facilities, and all driveline critical components such as clutch packs and planetary gear sets were then rated based on overall condition as compared to new components. Torque converters from each unit were cut open in an effort to determine the condition of the internal stator/one-way clutch assembly, as well as the lockup friction disk and reaction plate. After the inspection was complete and all data collected, parts were displayed for inspection by TARDEC and ATI representatives.

3.0 TRANSMISSION COMPONENT INSPECTION

The three transmissions can be split into two groups based on overall internal component condition. First, SN455 had experienced severe heat, and thus had incurred the most internal damage resulting in some glazed/burned friction disks and various melted plastic speed sensors. The second group, comprised of SN719 and SN160, were found to be in good condition with no major clutch damage or obvious signs of exposure to extreme heat. In all transmissions, C1 and C4 clutch packs were found to have damage that varied from none to mild. From the initial inspection, no apparent cause of failure was indicated based on the condition of the internal components. Findings are listed below by individual transmission serial number.

SN455

The following is a listing of internal component condition as found during teardown and inspection on SN455:

- Transmission had experienced high temperatures, evident by the discoloration and odor of the used fluid when drained.
- All plastic speed sensors had melted housings.
- Plastic debris found in oil pan (attributed to melted sensors).

- Plastic debris filtering screen in valve body melted and deformed.
- C1 clutch pack had to be forcibly removed from the shaft during disassembly due to warped steel plates. C1 clutch contained darkened and moderately glazed friction disks. C4 friction disks had darkening of the inner radius and slightly polished steel plates. Remaining clutches varied from damage free to some light darkening.
- Planetary gears and carriers in excellent condition with no pitting or spalling of teeth.
- Oil pump housing and gears measured within specified tolerances and showed no visual signs of unusual wear (measured values are presented in Appendix A).
- Torque converter completely blued/blackened with measured endplay outside of specs.
- Factory installed suction filter had been replaced and magnet was missing between filter and transmission housing.
- All shift solenoid and temperature sender resistances measured within specs (measured values are in Appendix A).

Figure 1 below shows SN455 C1 clutch pack damage. Steel reaction plates were warped and contained hot spots on the reaction surface. Friction disks were burnt and darkened, but remained intact without any chipping or flaking of the friction surface. C1 clutch pack clearance was found to be minimal due to the warped steel plates.

Figure 1 - SN455 C1 Friction Disks and Reaction Plates

Figure 2 below shows SN455 C4 clutch pack damage. Overall condition was good with some mild darkening of the inner radius of the friction disks. Component rating information on clutch packs and planetary gear sets, along with pictures of all clutch packs for SN455 can be found in Appendix A.

Figure 2 - SN455 C4 Friction Disks and Reaction Plates

SN719

The following is a listing of internal component condition as found during teardown and inspection on SN719:

- Some mild darkening of various clutch pack friction disks, primarily on C1 and C4 clutch packs. Several friction disks still retained factory writing indicating very little wear. Overall clutch pack condition was good.
- Planetary gears and carriers in excellent condition with no pitting or spalling of the teeth.
- Oil pump housing and gears measured within specified tolerances and showed no visual signs of unusual wear (measured values are presented in Appendix B).
- Torque converter showed signs of bluing around lock up mechanism area with measured endplay at the limit for new component specs.
- Still had factory installed suction filters (noted by green dot applied by ATI during manufacturing) and magnet installed between suction filter and transmission housing.
- All shift solenoid and temperature sender resistances measured within specs (measured values are in Appendix B).

Figure 3 below shows SN719 C1 clutch pack. Overall clutch condition was excellent with minimal to no darkening of the friction disks.

Figure 3 - SN719 C1 Friction Disks and Reaction Plates

Figure 4 below shows SN719 C4 clutch pack. Overall condition was found to be slightly better than SN455, but still contained darkening of the friction disk inner radius. Component rating information on clutch packs and planetary gear sets, along with pictures of all clutch packs for SN719 can be found in Appendix B.

Figure 4 – SN719 C4 Friction Disks and Reaction Plates

SN160

The following is a listing of internal component condition as found during teardown and inspection on SN160:

- Some mild darkening of the C1 clutch pack friction material. Most friction disks still retained factory writing indicating very little wear. Overall clutch pack condition was excellent; best overall condition of the three units.
- Planetary gears and carriers in excellent condition with no pitting or spalling of the teeth.
- Oil pump housing and gears measured within specified tolerances and showed no visual signs of unusual wear (measured values are presented in Appendix C).
- Torque converter showed signs of bluing around lock up mechanism area with measured endplay well within specs.
- Still had factory installed suction filters (noted by green dot applied by ATI during manufacturing) and magnet installed between suction filter and transmission housing.
- All shift solenoid and temperature sender resistances measured within specs (measured values are in Appendix C).

Figure 5 below show SN160 C1 clutch pack. Condition of all clutches found to be in excellent condition. Component rating information on clutch packs and planetary gear sets, along with pictures of all clutch packs for SN160 can be found in Appendix C

Figure 5 - SN160 C1 Friction Disks and Reaction Plates

4.0 TORQUE CONVERTER COMPONENT INSPECTION

Upon completion of the initial teardown, no apparent cause for transmission malfunction was found. It was noted during disassembly that all three torque converters were discolored due to high temperatures, and ranged from lightly blued to black in color. This combined with measured maximum torque converter endplay for two of the units at or exceeding limits set by ATI, called for further investigation on torque converter condition. TFLRF staff requested permission from TARDEC to cut open each converter to assess internal condition. TARDEC granted permission, and each converter was disassembled for further analysis. Torque converter disassembly was accomplished by mounting each unit in a metal lathe and cutting the welded seam open around the circumference of its housing as shown in Figure 6.

Figure 6 - Torque Converter Mounting in Metal Lathe

After cutting, the torque converter was opened for inspection. All internal torque converter components were visually inspected for damage and their overall condition assessed. Findings are listed below by individual transmission serial number.

SN455

During initial transmission disassembly, the endplay of the each converter was measured in an effort to determine the cause of failure. The measurement apparatus can be seen below in Figure 7.

Figure 7 - Torque Converter Endplay Measurement Apparatus

Table 1 below lists the limits set forth by ATI for torque converter endplay and pump hub dimensions, as well as the measured values from SN455.

Table 1 - SN455 Torque Converter Measurements

	Spec (in)	Measured (in)
Maximum TC Endplay, New	0.0300	0.047
Maximum TC Endplay, Used	0.0400	
Converter Pump Hub		
Minimum OD	2.2933	2.2945
Minimum Distance Between Flats	2.0351	2.0440

The following is a listing of internal component condition as found during disassembly and inspection on SN455:

- Measured torque converter endplay beyond ATI maximum specs.
- Darkened lockup clutch friction disk and mild to moderate hot spots on steel reaction surface.
- Plastic turbine housing support bushing/thrust washer intact.
- Stator one-way clutch seized, with heavy scoring on retainer plate.

As to be expected from previous findings, the lockup clutch friction plate and reaction surface both showed signs of exposure to high temperatures. Although darkened, the friction disk showed no signs of chipping or flaking on the friction material as seen below in Figure 8.

Figure 8 - SN455 Lockup Friction Plate

The steel reaction plate showed some mild signs of damage with minor polishing and various hot spots as shown in Figure 9.

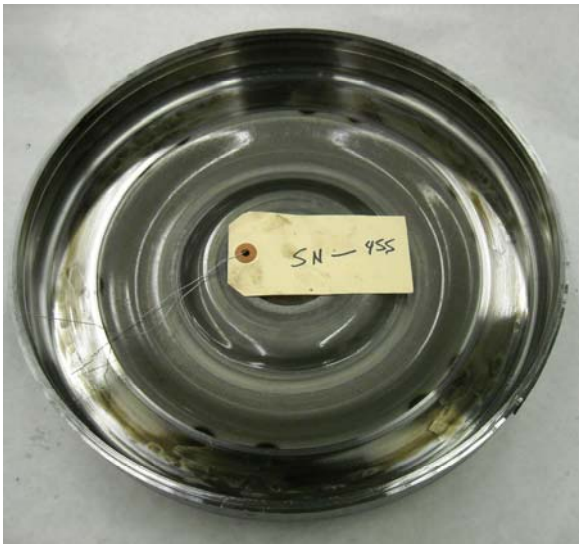


Figure 9 - SN455 Lockup Reaction Plate

It was determined that a damaged or malfunctioning stator is the likely cause of the transmission failure. Stator operation is discussed further in the Operational Effects of Failure section. Upon disassembly of the stator, the retainer plate was removed also revealing a seizure of the one-way clutch assembly as shown in Figure 10.

Figure 10 - SN455 Stator Clutch Assembly

Ordinarily there is no relative motion between the retainer plate and outer area of the one-way clutch, as the one-way clutch assembly is a press fit within the stator wheel. It was

found that in SN455 there has been considerable relative motion between the two surfaces, evident by scarring and wear of the retainer plate and outer one-way clutch assembly. Retainer plate wear is shown below in Figure 11.

Figure 11 - SN455 Retainer Plate Wear

This relative motion between each surface is likely caused by expansion of the outer stator turbine wheel due to excessive heat, allowing the entire one-way clutch assembly to rotate within the stator wheel. It is possible that the one-way clutch itself was functioning until wear material entered the assembly from the reaction plate causing the doglegs to gall and seize.

SN719

Consistent with SN455, endplay and pump hub dimensions of SN719's torque converter were measured in an effort to determine the cause of failure; measured values are listed below in Table 2.

Table 2 - SN719 Torque Converter Measurements

	Spec (in)	Measured (in)
Maximum TC Endplay, New	0.0300	0.030
Maximum TC Endplay, Used	0.0400	
Converter Pump Hub		
Minimum OD	2.2933	2.2975
Minimum Distance Between Flats	2.0351	2.0450

The following is a listing of internal component condition as found during disassembly and inspection on SN719:

- Measured endplay of torque converter at maximum specs for new converters.
- Moderately darkened lockup clutch friction disk with mild polishing on steel reaction surface.
- Plastic turbine housing support bushing/thrust washer broken into three pieces.
- Stator one-way clutch seized with moderate to heavy scoring on retainer plate.

As seen below in Figure 12, SN719 lockup clutch friction plate was found to be in good condition with only some mild darkening. It was noted that a few small chips in the friction material surface was found along the outer edge, but it is unknown if this occurred from use or during disassembly and handling.

Figure 12 - SN719 Lockup Friction Plate

The lockup clutch reaction plate was found to be in good condition with no evidence of polishing or hot spots as shown below in Figure 13.

Figure 13 - SN719 Lockup Reaction Plate

Consistent with SN455, the failure in transmission SN719 was attributable to a damaged or malfunctioning stator assembly. As shown below in Figure 14 and Figure 15, like SN455, the retainer plate and one-way clutch assembly has moved relative to one another causing severe wear on both surfaces. Again, a complete seizure of the one-way clutch was found, likely due to galled doglegs in the assembly.

Figure 14 - SN719 Stator Clutch Assembly

Figure 15 - SN719 Retainer Plate Wear

In addition to the failed stator, SN719 was also found to have a broken turbine housing support bushing/thrust washer as shown below in Figure 16. It is likely that this was caused by other problems (i.e. lockup clutch chatter, heat, etc), and is a result of the overall failure and not a cause.

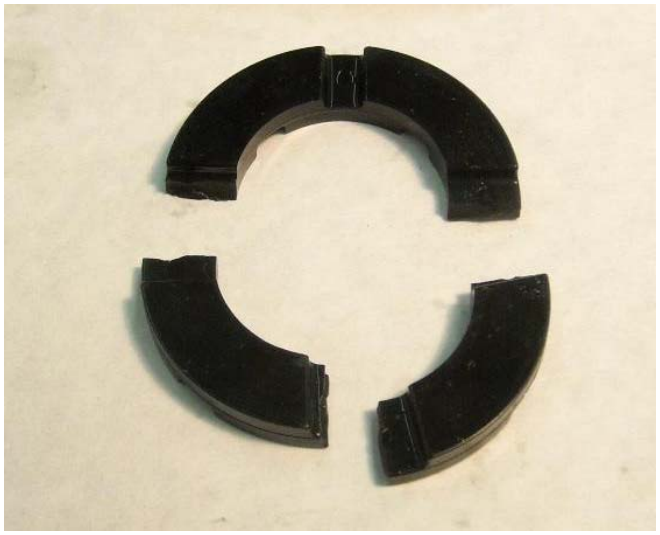


Figure 16 - SN719 Turbine Housing Support Bushing/Thrust Washer

SN160

Consistent with the above, endplay and pump hub dimensions of SN160's torque converter was measured in an effort to determine the cause of failure; measured values are listed below in Table 3.

Table 3 - SN160 Torque Converter Measurements

	Spec (in)	Measured (in)
Maximum TC Endplay, New	0.0300	0.017
Maximum TC Endplay, Used	0.0400	
Converter Pump Hub		
Minimum OD	2.2933	2.295
Minimum Distance Between Flats	2.0351	2.0445

The following is a listing of internal component condition as found during disassembly and inspection on SN160:

- Measured endplay of torque converter within ATI published specs.
- Lightly darkened lockup clutch friction disk with excellent steel reaction surface.
- Plastic turbine housing support bushing/thrust washer intact.
- Stator one way clutch in working order with light to moderate scoring on retainer plate.

SN160 lockup clutch assembly was found to be in like new condition, with little to no darkening of the friction material, and no polishing or hot spots present on the reaction plate. SN160's lockup friction disk and reaction plate can be seen below in Figure 17 and Figure 18 respectively.

Figure 17 - SN160 Lockup Clutch Friction Plate

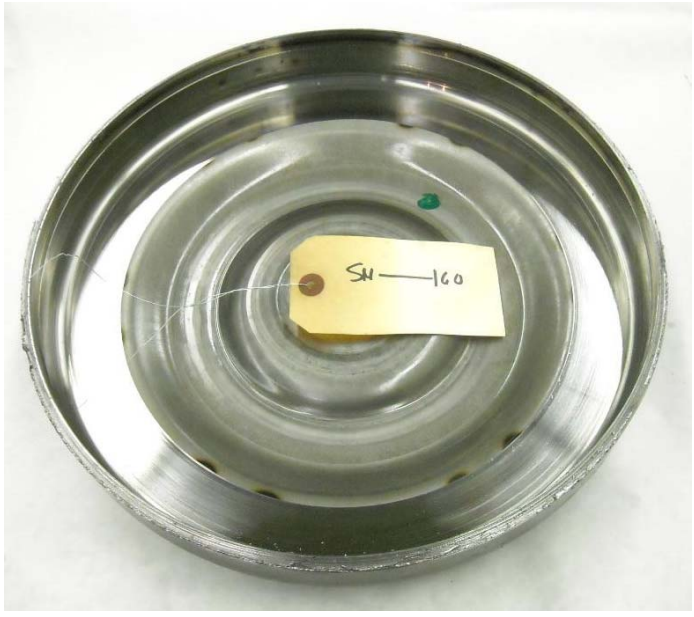


Figure 18 – SN160 Lockup Clutch Reaction Plate

Like SN455 and SN719, the failure is attributable to a malfunctioned stator assembly on SN160. However, differences existed between the severity of wear found, and overall condition when compared with the two previous units. Again there was evidence of relative motion between the retainer plate and outer housing of the one-way clutch, but not to the severity of the other units. Like before, it is likely that high temperature caused the expansion of the stator turbine wheel and allowed the one-way clutch assembly to free spin within the stator turbine wheel. From the damage found, it appears as if this unit was removed from service more quickly, as the wear on the retainer plate is minimal. Different from the previous units, the one-way clutch was found to still be operable and did not show signs of premature wear. Figure 19 below shows SN160 stator and one-way clutch assembly.

Figure 19 - SN160 Stator Clutch Assembly

Similar to the previous retainer plates, the wear patterns on SN160's retainer plate were consistent and showed similar high and low wear areas on its surface. SN160's retainer plate can be seen below in Figure 20.

Figure 20 - SN160 Retainer Plate Wear

It is likely that with continued use, SN160's retainer plate would continue to wear against the one-way clutch causing wear metals to enter the one-way clutch assembly resulting in an eventual seizure consistent with SN455 and SN719.

5.0 OPERATIONAL EFFECTS FAILURE

The torque converters stator assembly is used to redirect the working fluid from the turbine back into the pump vanes when differential speed between the pump and turbine are high. The one-way clutch allows the stators turbine blades to oppose the force of the fluid, and redirect it back into the vanes of the pump. This is due to the force of the fluid acting in opposition to the direction that the one-way clutch will allow the stator turbine to freewheel. This allows for the torque multiplication of the torque converter and aides in providing moving force from a standstill. Once the pump and turbine speeds approach a 1:1 ratio, the stators one-way clutch allows the stators turbine wheel to free spin within the fluid coupling. Two types of failures can occur within the stator assembly, freewheeling, or a complete seizure. In a freewheeling stator scenario, the stator assembly will not be able to oppose the force of the fluid leaving the turbine, and thus cannot

redirect the fluid back into the pump. This circumvents the torque multiplication process, and leaves the vehicle with little to no acceleration from a standstill. In contrast, a seized stator wheel will work properly at low vehicle speeds when the differential speeds between the pump and turbine are high, but will cause problems when speeds get close to 1:1. As the pump and turbine relative speeds approach 1:1, the stator will impede the fluid coupling if it is unable to free spin, and will causes a drastic reduction in torque converter efficiency and increase fuel consumption and working fluid temperature.

6.0 OIL ANALYSIS

Used oil samples that were collected prior to disassembly were tested in accordance with American Society of Testing Materials (ASTM) test procedures in an effort to determine fluid characteristics. Table 4 below lists each procedure completed on the used oil samples.

Table 4 – Used Fluid Chemical Analysis Procedures

Test Method	Description
ASTM D445	Kinematic Viscosity @100°C
ASTM D5185	Wear Metals by ICP
ASTM D664	Total acid number
ASTM D4739	Total base number
ASTM E168 FTIR	Infrared Spectra - Fingerprint

Results from ASTM D5185, Wear Metals by ICP, will indicate any contamination of the transmission fluid with engine oil, as concentration levels of elements common to engine oil additive packages will be elevated. All chemical analysis results can be seen below in Table 5.

Table 5 - Used Fluid Chemical Analysis Results

Results of the Analytical Evaluations of the Fluid

	Sample Code	CL08-00552	CL08-00553	CL08-00554
ASTM Methods		**SN6310824455**	**SN6310817719**	**SN6310817160**
D445 Viscosity at 100C	cSt	5.91	6.94	6.83
D4739 Total Base Number				
Buffer End Point	mg KOH/g	0.54	0.85	0.82
D5185 Metals by ICP				
Aluminum	ppm	36	10	3
Antimony	ppm	<1	<1	<1
Barium	ppm	2	1	2
Boron	ppm	94	94	103
Calcium	ppm	46	112	93
Chromium	ppm	<1	<1	<1
Copper	ppm	18	10	11
Iron	ppm	28	13	12
Lead	ppm	20	3	4
Magnesium	ppm	1	1	3
Manganese	ppm	3	1	1
Molybdenum	ppm	<1	<1	<1
Nickel	ppm	<1	<1	<1
Phosphorus	ppm	226	300	298
Silicon	ppm	11	6	4
Silver	ppm	<1	<1	<1
Sodium	ppm	6	14	7
Tin	ppm	<1	<1	<1
Zinc	ppm	8	9	6
Potassium	ppm	<5	9	7
Strontium	ppm	<1	<1	<1
Vanadium	ppm	<1	<1	<1
Titanium	ppm	<1	<1	<1
Cadmium	ppm	<1	<1	<1
D664 Total Acid Number				
Buffer End Point	mg KOH/g	0.97	0.81	0.77
E168 FTIR		Appendix D	Appendix D	Appendix D

From the results, the overall concentration of zinc warrants immediate attention. Engine oils typically have a 1:1 ratio of zinc and phosphorus where they are used as anti-wear inhibitors. Although phosphorus shows up in the 225-300 ppm ranges, zinc levels remained low at less than 10 ppm. Calcium also raises questions with used oil concentrations measuring in the 50-100 ppm ranges. Typical engine oils contain calcium levels in the 2000 ppm plus range. Viscosity measured from the samples was inconclusive, as engine oil viscosity varies with grade. Lastly, examination of total base number (TBN) and total acid number (TAN) gives information regarding overall condition of the oil. While the sample removed from SN455 had a slightly higher acid and slightly lower base number, none of the used oils had what would be considered excessive TAN content. In addition, TBN values were found to be lower than typical engine oils. FTIR traces were almost identical, with some small differences in peak shape and magnitude at around 1725 cm-1 wavenumber. Complete FTIR traces can be seen for each fluid sample in Appendix D.

In conclusion, TFLRF staff feel the stator failures experienced by all three transmissions are not related to the fluid. From the detailed chemical analysis, no evidence of engine oil was found in the used oil samples and supports that all failed units were filled with Dexron or TES-295 like fluids.

7.0 PARTS INSPECTION MEETING

A parts inspection meeting was hosted by SwRI after TFLRF staff completed the disassembly on each transmission, and all drive line critical components were visually inspected and rated. Representatives from TARDEC and ATI were present to discuss findings, inspect the components, and discuss further actions if found necessary. During the meetings, details of the RG31’s manufacturing and history, overall specifications, possible operating conditions, and the limited description of the failures were discussed. From the discussions, it was conveyed that ATI’s stance supports TFLRF staff’s findings that the cause of failure is not related to the fluid used. Furthermore, ATI has requested that two of the three torque converters be sent to their internal product engineering team to further investigate the cause of failure. ATI hopes to determine the temperature

required to blue/blacken the torque converter housing in an effort to quantify fluid temperatures experienced by the failed components. TARDEC and TFLRF have agreed to release the torque converters to ATI in exchange for their official comments on further findings.

8.0 CONCLUSION

It is the opinion of TFLRF staff, that from the provided description of failure and the information gained through component inspection, it appears that the one-way clutch assembly in each transmission's torque converter was allowed to free spin within the stator turbine wheel due to expansion from high temperatures. This yielded a freewheeling stator scenario and provided no torque multiplication and little to no acceleration of the vehicle during use. Due to the spinning of the one-way clutch assembly against the retainer plate, wear metals were introduced into the one-way clutch mechanism, causing it to seize. It is likely that given continued use, SN160's one-way clutch would have also seized in a similar manner as SN455 and SN719. The source of the high temperatures is unknown, and could be attributable to a number of causes such as inappropriately sized equipment, overloaded vehicles, and extreme operating and ambient conditions. Overall condition of the remaining internal transmission components was found to be in good to excellent condition. Some mild to moderate clutch damage was found in SN455, but is likely attributable to the extreme fluid temperatures it experienced, and is not considered a cause of failure. It is the opinion of TFLRF staff that the failures experienced were not attributable to the use of a non-standard fluid, but are more in line with a possible design or application error. Furthermore, from the used oil analysis, TFLRF staff believe that there was no engine oils present in the used fluid drained from each transmission, and analysis results remain consistent with a used Dexron or TES-295 fluids.

APPENDIX A

Inspection and Analysis of Failed Transmissions

Work Directive No. 51

Allison 2500-SP
SN6310824455

Conducted for

U.S. Army RDECOM
Tank-Automotive Research, Development & Engineering Center
Force Projection Technologies
Warren, Michigan 48397-5000

Measured values for main transmission oil pump can be seen in the table shown below:

Charging Pump	Spec (in)	Measured (in)
Bushing, Maximum ID	2.2989	2.299
Gear Cavity, Maximum Depth	0.9819	0.820
Gear Cavity, Maximum ID	4.2989	4.325
Driven Gear, Max Diametric Clearance w/ Pump Body	0.008	0.006
Driven Gear, Max Tooth Clearance w/ Crescent	0.0179	0.013
Driven Gear, Min OD	4.3302	4.341
Wear Plate, Min Thickness	0.1161	0.118
Gear-to-Wear Plate, Maximum Side Clearance	0.0022	0.002
Drive Gear, Maximum Distance Between Flats	2.0537	2.048

Each clutch pack (friction disk and reaction plates) is shown below in sequential order from C1 to C5. SN455 experienced the most clutch damage due to high fluid temperatures. C1 clutch pack had to be forcibly removed from the transmission due to warped reaction plates.

SN455 C1 Friction Disk and Reaction Plates

SN455 C2 Friction Disk and Reaction Plates

SN455 C3 Friction Disk and Reaction Plates

SN455 C4 Friction Disk and Reaction Plates

SN455 C5 Friction Disk and Reaction Plates

TRANSMISSION SERIAL NUMBER ENIDNG IN 455

C1 CLUTCH STEEL PLATES	WARPAGE OF CLUTCH PLATES, HAD TO BE REMOVED BY FORCE
C1 CLUTCH PAPER PLATES	WARPAGE OF CLUTCH PLATES, HAD TO BE REMOVED BY FORCE, PLATES ARE DARKENED WITH SOME GLAZING
C2 CLUTCH STEEL PLATES	SLIGHTLY POLISHED WITH NO ABNORMAL WEAR
C2 CLUTCH PAPER PLATES	SLIGHT BROWN DISCOLORATION
C3 CLUTCH STEEL PLATES	SLIGHT POLISHING WITH SOME HEAT SPOTS
C3 CLUTCH PAPER PLATES	VERY SLIGHT DARKENING
C4 CLUTCH STEEL PLATES	SLIGHTLY POLISHED WITH NO ABNORMAL WEAR
C4 CLUTCH PAPER PLATES	DARKENING IN INNER RADIUS OF THE PLATES WITH PLATE IDENTIFICATION NUMBERS VISBLE
C5 CLUTCH STEEL PLATES	SLIGHTLY POLISHED WITH NO ABNORMAL WEAR
C5 CLUTCH PAPER PLATES	VERY SLIGHT DARKENING WITH PLATE IDENTIFICATION NUMBERS VISIBLE
THRUST WASHER	LIGHT WEAR, POLISHED WITH SOME LIGHT DEPOSITS AND CORROSION
BUSHINGS	SLIGHT POLISHING WITH NO ABNORMAL WEAR
FRONT PUMP	NO ABNORMAL DETERIORATION OR WEAR, 60% PHOSPHATE COATING REMAINING ON PUMP GEAR TEETH
CARRIERS AND GEARS	NO ABNORMAL DETERIORATION OR WEAR, SOME POLISHING ON GEAR TEETH
SEALS	SOFT AND PLIABLE
SPEED SENSORS	ALL THREE PLASTIC (?) SENSORS HAVE HEAT DAMAGE

Component rating information supplied courtesy of Southwest Research Institute Technical Advisor, Ray Townsend

APPENDIX B

Inspection and Analysis of Failed Transmissions

Work Directive No. 51

Allison 2500-SP
SN6310817719

Conducted for

U.S. Army RDECOM
Tank-Automotive Research, Development & Engineering Center
Force Projection Technologies
Warren, Michigan 48397-5000

Measured values for main transmission oil pump can be seen in the table shown below:

Charging Pump	Spec (in)	Measured (in)
Bushing, Maximum ID	2.2989	2.300
Gear Cavity, Maximum Depth	0.9819	0.810
Gear Cavity, Maximum ID	4.2989	4.335
Driven Gear, Max Diametric Clearance w/ Pump Body	0.008	0.005
Driven Gear, Max Tooth Clearance w/ Crescent	0.0179	0.009
Driven Gear, Min OD	4.3302	4.345
Wear Plate, Min Thickness	0.1161	0.121
Gear-to-Wear Plate, Maximum Side Clearance	0.0022	0.002
Drive Gear, Maximum Distance Between Flats	2.0537	2.159

Each clutch pack (friction disk and reaction plates) is shown below in sequential order from C1 to C5. SN719 only experienced minor clutch damage, primarily C1 and C4, but was overall found to still be in operable condition.

SN719 C1 Friction Disk and Reaction Plates

SN719 C2 Friction Disk and Reaction Plates

SN719 C3 Friction Disk and Reaction Plates

SN719 C4 Friction Disk and Reaction Plates

SN719 C5 Friction Disk and Reaction Plates

TRANSMISSION SERIAL NUMBER ENIDNG IN 719

C1 CLUTCH STEEL PLATES	SLIGHTLY POLISHED WITH NO ABNORMAL WEAR
C1 CLUTCH PAPER PLATES	VERY SLIGHT DARKENING WITH PLATE IDENTIFICATION NUMBERS VISIBLE
C2 CLUTCH STEEL PLATES	SLIGHTLY POLISHED WITH NO ABNORMAL WEAR
C2 CLUTCH PAPER PLATES	VERY SLIGHT DARKENING WITH PLATE IDENTIFICATION NUMBERS VISIBLE
C3 CLUTCH STEEL PLATES	POLISHED WITH NO ABNORMAL WEAR
C3 CLUTCH PAPER PLATES	VERY SLIGHT DARKENING WITH PLATE IDENTIFICATION NUMBERS VISIBLE
C4 CLUTCH STEEL PLATES	POLISHED WITH NO ABNORMAL WEAR
C4 CLUTCH PAPER PLATES	DARKENING IN INNER RADIUS OF THE PLATES WITH PLATE IDENTIFICATION NUMBERS VISBLE
C5 CLUTCH STEEL PLATES	VERY SLIGHTLY POLISHED WITH NO ABNORMAL WEAR
C5 CLUTCH PAPER PLATES	VERY SLIGHT DARKENING WITH PLATE IDENTIFICATION NUMBERS VISIBLE
THRUST WASHER	LIGHT WEAR, HAS SOME BLACK DEPOSITS
BUSHINGS	SLIGHT POLISHING WITH NO ABNORMAL WEAR
FRONT PUMP	NO ABNORMAL DETERIORATION OR WEAR, 60% PHOSPHATE COATING REMAINING ON PUMP GEAR TEETH
CARRIERS AND GEARS	NO ABNORMAL DETERIORATION OR WEAR, SOME POLISHING ON GEAR TEETH
SEALS	SOFT AND PLIABLE

Component rating information supplied courtesy of Southwest Research Institute Technical Advisor, Ray Townsend

APPENDIX C

Inspection and Analysis of Failed Transmissions

Work Directive No. 51

Allison 2500-SP
SN6310817160

Conducted for

U.S. Army RDECOM
Tank-Automotive Research, Development & Engineering Center
Force Projection Technologies
Warren, Michigan 48397-5000

Measured values for main transmission oil pump can be seen in the table shown below:

Charging Pump	Spec (in)	Measured (in)
Bushing, Maximum ID	2.2989	2.298
Gear Cavity, Maximum Depth	0.9819	0.881
Gear Cavity, Maximum ID	4.2989	4.323
Driven Gear, Max Diametric Clearance w/ Pump Body	0.008	0.006
Driven Gear, Max Tooth Clearance w/ Crescent	0.0179	0.008
Driven Gear, Min OD	4.3302	4.300
Wear Plate, Min Thickness	0.1161	0.116
Gear-to-Wear Plate, Maximum Side Clearance	0.0022	0.005
Drive Gear, Maximum Distance Between Flats	2.0537	2.045

Each clutch pack (friction disk and reaction plates) is shown below in sequential order from C1 to C5. SN160 was found to be in the best overall condition. No clutches showed signs of major damage. Many friction disks retained the factory stampings indicating very minimal use.

SN160 C1 Friction Disk and Reaction Plates

SN160 C2 Friction Disk and Reaction Plates

SN160 C3 Friction Disk and Reaction Plates

SN160 C4 Friction Disk and Reaction Plates

SN160 C5 Friction Disk and Reaction Plates

TRANSMISSION SERIAL NUMBER ENIDNG IN 160

C1 CLUTCH STEEL PLATES	POLISHED WITH NO ABNORMAL WEAR
C1 CLUTCH PAPER PLATES	PLATE IDENTIFICATION NUMBERS VISIBLE WITH NO VISUAL WEAR OR DISTRESS
C2 CLUTCH STEEL PLATES	POLISHED WITH NO ABNORMAL WEAR
C2 CLUTCH PAPER PLATES	VERY SLIGHT DARKENING WITH PLATE IDENTIFICATION NUMBERS VISBLE
C3 CLUTCH STEEL PLATES	SLIGHTLY POLISHED WITH NO ABNORMAL WEAR
C3 CLUTCH PAPER PLATES	VERY SLIGHT DARKENING WITH PLATE IDENTIFICATION NUMBERS VISBLE
C4 CLUTCH STEEL PLATES	SLIGHTLY POLISHED WITH NO ABNORMAL WEAR
C4 CLUTCH PAPER PLATES	VERY SLIGHT DARKENING WITH PLATE IDENTIFICATION NUMBERS VISBLE
C5 CLUTCH STEEL PLATES	SLIGHTLY POLISHED WITH NO ABNORMAL WEAR
C5 CLUTCH PAPER PLATES	VERY SLIGHT DARKENING WITH PLATE IDENTIFICATION NUMBERS VISBLE
THRUST WASHER	POLISHED WITH SOME BLACK DEPOSITS
BUSHINGS	SLIGHT POLISHING WITH NO ABNORMAL WEAR
FRONT PUMP	NO ABNORMAL DETERIORATION OR WEAR, ALL PHOSPHATE COATING REMAINING ON PUMP GEAR TEETH
CARRIERS AND GEARS	NO ABNORMAL DETERIORATION OR WEAR, SOME POLISHING ON GEAR TEETH
SEALS	SOFT AND PLIABLE

Component rating information supplied courtesy of Southwest Research Institute Technical Advisor, Ray Townsend

APPENDIX D

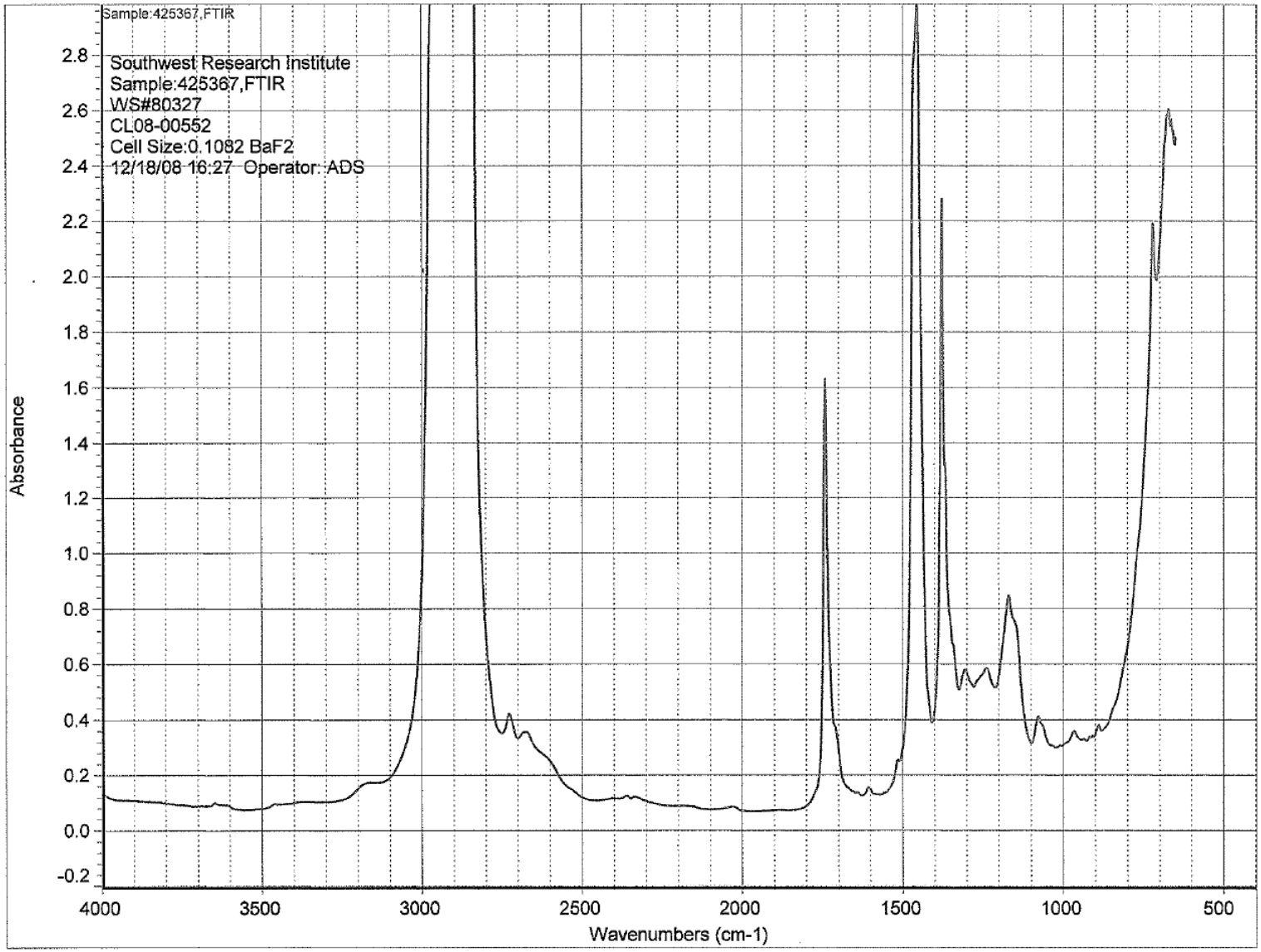
Inspection and Analysis of Failed Transmissions

Work Directive No. 51

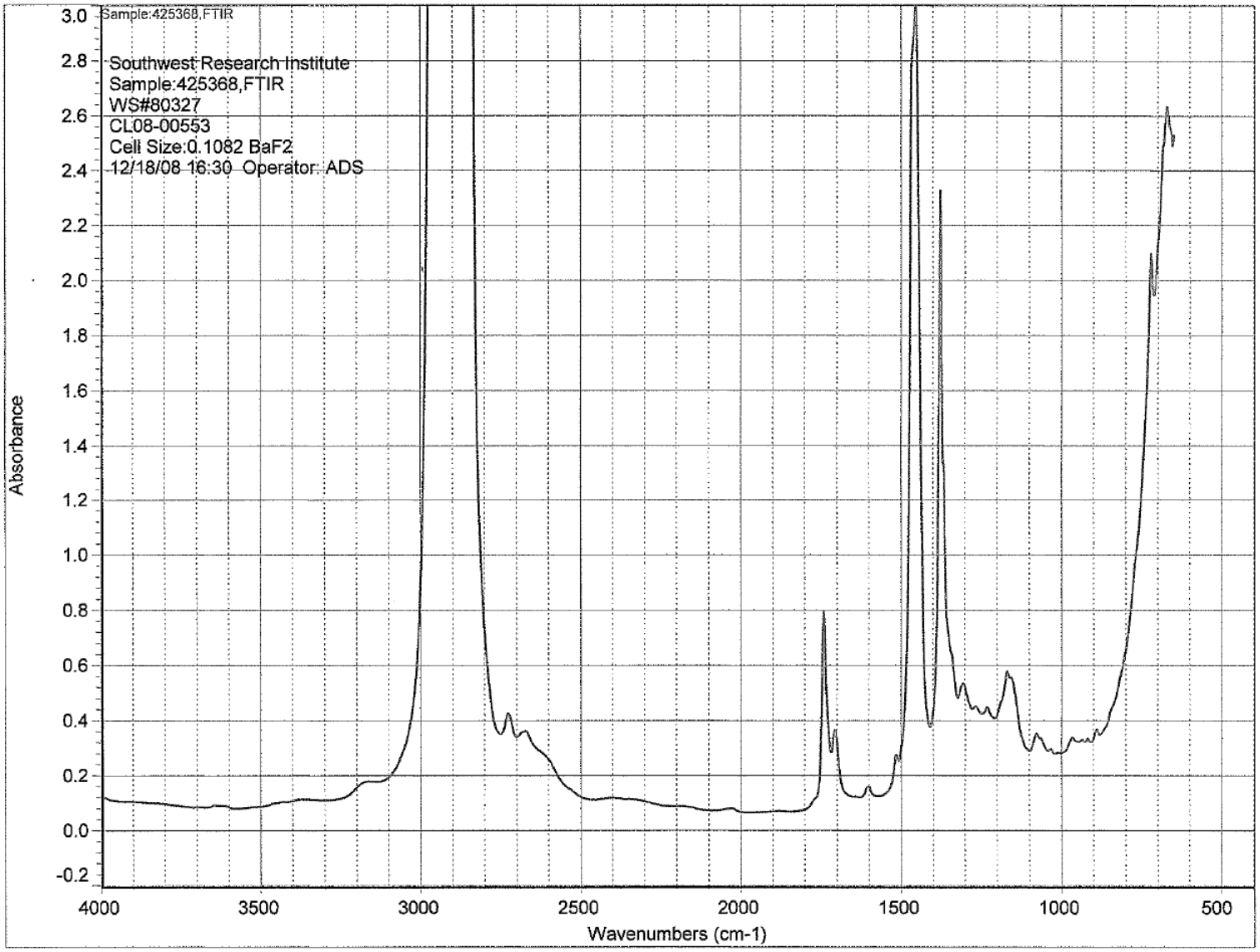
Used Oil Analysis FTIR Traces

Conducted for

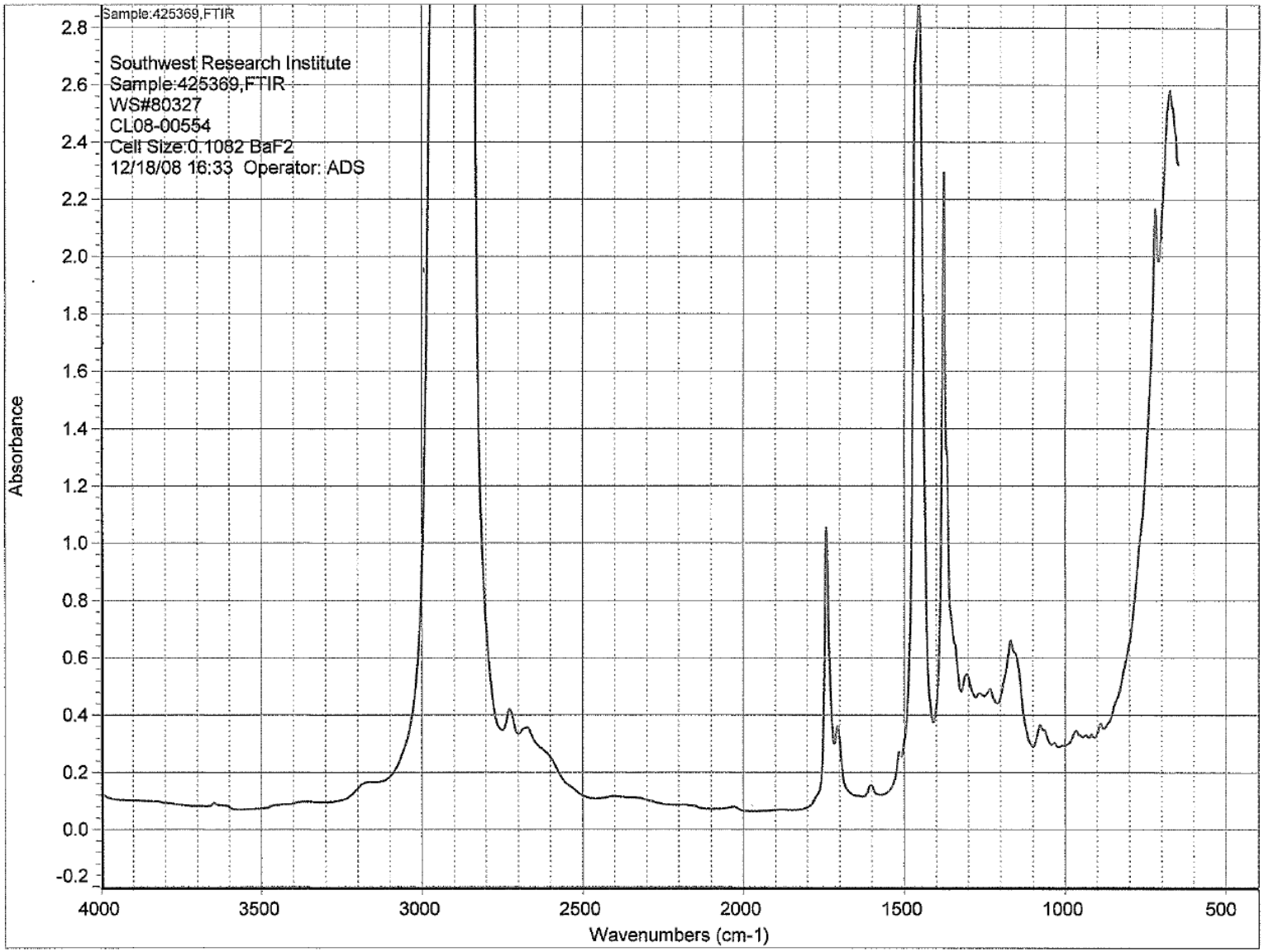
U.S. Army RDECOM
Tank-Automotive Research, Development & Engineering Center
Force Projection Technologies
Warren, Michigan 48397-5000



FTIR Trace of SN455 Used Oil



FTIR Trace of SN719 Used Oil



FTIR Trace of SN160 Used Oil